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REPORTS
HABER, D.F.

ANALYSIS OF DATA ON ROAD SURFACE PERFORMANCE ON A LOW VOLUME FOREST ROAD IN HORSE CREEK WITH LOG HAUL AND LIGHT VEHICLE TRAFFIC

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COMPLETION REPORT

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INTRODUCTION

According to the USFS cost records[1], aggregate replacement accounts for approximately two thirds of the maintenance cost for typical low volume aggregate forest roads. Predication of the aggregate replacement costs due to logging truck travel vs. general public travel is of importance to many forests because of requirements to "cost share" replacement costs with private logging companies. Although attempts to model aggregate loss due to logging and general traffic have been made, very few detailed North American field studies are available to calibrate the aggregate replacement models. Previously reported studies are of short duration and measured losses were close to the measurement accuracy [2] until a study just completed which was contracted by the Forest Service to NATCE in 1993 and reported in June 1994[4] .

In 1978, the US Forest Service, Region One set up a road site in the Horse Creek Study Area in the Nez Perce NF to find: (1) a method of predicting subgrade moisture to allow consideration of seasonal variations in subgrade strength for aggregate thickness design and (2) to monitor the effects of timber haul on the aggregate surfacing.

At appropriate intervals from 1978 to 1982, road surfacing data, subgrade moisture data , and various weather parameters were measured. Total traffic both log truck and general traffic was recorded. Results of the subgrade moisture investigation has been completed and was presented in a report by Hinshaw and Northrup in 1991[5]. The road surfacing data was not analyzed until this project started in 1993.

STUDY OBJECTIVES

The major objective of this study is to provide a detailed analysis of road cross-section data to determine a prediction of the aggregate loss and to examine the relationship between aggregate loss and logging truck traffic and general traffic volume.

Other objectives are:

(1) examine collected roughness data for correlation to cross-section measurements. That is, determine the correlation between rutting and surface roughness.

(2) compare aggregate loss calculated from cross-section data to losses predicted by models such as the HDM World Bank Model, National Forest Aggregate Design Model, and other "rule of the thumb" models used by the Nez Perce NF.

(3) Compare measured road roughness generated by traffic and environmental factors to that predicted by the HDM Model.

PROJECT DESCRIPTION

The test road is located approximately 35 air miles east of Grangeville, Idaho. The road is a single-lane, aggregate-surfaced logging road with a 12-foot top width. The 1.2-mile road was surfaced in three segments with 4, 8, and 12 inches of good quality, dense-graded, crushed rock. Road grades range from -6.4 to +5.6 percent. Major traffic on the test road was related to timber haul.

Topographic and climatic characteristics were as follows:

Elevation	-	5,500 feet above sea level.
Topography	-	10 to 45 percent sideslopes near top of a ridge in mountainous terrain.
Temperature	-	Average annual precipitation - 49 inches, 72 percent occurring as snow.
Vegetation	-	Moderately heavy fir and pine forest.

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CROSS-SECTION DATA

At the 25 test locations, fabric was placed in the subgrade along short sections of the road so at each test location cross-sections could be taken (approximately ten feet apart) on a fabric section and non-fabric section. Approximately fifty cross-sections were taken by rod and level on pre-established 1-foot intervals across the road generally 18 ft. for each cross-section. Cross-sections were normally taken at the beginning of the haul season (as soon as the road was open to traffic) the end of the season and before and after blading. Sets were taken as follows:

TABLE 1

YEAR	DATE	
1978	9/13	begin cross-sections
1978	11/6	after light grading
1979	6/18	beginning of season
1979	7/5	after grading
1979	10/24	after light grading
1980	5/13	beginning of season
1980	6/18	after heavy traffic
1980	7/5	after heavy traffic
1980	7/19	before grading
1980	7/22	after grading
1980	8/4	before grading
1980	8/6	after grading
1980	9/10	before grading
1980	9/12	after grading
1980	10/11	end of season
1981	5/28	beginning of season
1981	6/16	after grading

1981	7/24	before grading
1981	7/31	after grading
1981	8/29	
1981	9/12	before grading
1981	9/26	after grading
1982	6/28	beginning of season
1982	7/20	before grading
1982	7/21	after grading
1982	10/23	end of test

Location of the cross-sections was influenced by road curvature, grade and surface aggregate thickness. Table 2 summarizes these factors for the test locations.

TABLE 2

TEST NAME	LOCATION FROM START	CURVATURE	GRADE	AGGREGATE THICKNESS
MS 1&2	105 feet	radius 175 ft	-1.5%	8 inches
MS 3	408 feet	tangent	-3%	8 inches
MS 4	710 feet	radius 350 ft	-5%	8 inches
MS 5	840 feet	radius 350 ft	-5%	8 inches
I 4	1219 feet	straight	-3%	8 inches
I 5	1387 feet	straight	+1%	12 inches
MS 6&7	1562 feet	tangent	+5.5%	12 inches
I 7	1820 feet	radius 300 ft	-5%	12 inches
MS 8	2000 feet	straight	+1.5%	12 inches
I 8	2161 feet	tangent	+1.5%	12 inches
MS 9	2340 feet	radius 375 ft	-5%	12 inches
I 9	2560 feet	radius 375 ft	-5%	12 inches

MS 10	2950 feet	straight	+3.5%	12 inches
MS 11&12	3282 feet	straight	+0.5%	4 inches
I 11	3420 feet	straight	+1%	4 inches
I 12	3698 feet	radius 200 ft	+4%	4 inches
MS 13	4051 feet	tangent	+0%	4 inches
I 13	4154 feet	tangent	+1.5%	4 inches
MS 14	4380 feet	tangent	-1%	4 inches
MS 15	4525 feet	straight	-1.75%	4 inches
I 15	4595 feet	tangent	-1.5%	4 inches
MS 16	4910 feet	radius 210 ft	-6%	4 inches
MS 17	5050 feet	radius 210 ft	-2.5%	4 inches
I 17	5475 feet	straight	-1%	4 inches*
MS 18	5655 feet	straight	-2%	4 inches*

* Indicates asphalt surface treatment

ROAD ROUGHNESS DATA

Longitudinal roughness was monitored with a Cox electronic roughness meter mounted in a station wagon. Roughness measurements were generally taken before and after grading and at the beginning and end of the road travel season. Roughness measurements over the entire length of the road section were taken :

1980 - 2 sets

1981 - 8 sets

1982 - 2 sets

Roughness data was converted from the Cox measurements to QI values for comparison with other predictions of roughness by a calibration curve developed by Robert Hinshaw[5] in 1986 and shown in Appendix A. Data was taken over the following sections corresponding to changes in surfacing as shown in table 3.

TABLE 3

SURFACE TREATMENT	STATIONING	
8 in thickness	0 to 12+14	[0 to 1240 ft]
12 in thickness	12+14 to 30+62	[1240 to 3062 ft]
4 in thickness	30+62 to 53+33	[3062 to 5333 ft]
4 in thickness - asphalt surface treatment	53+33 to 66+55	[5333 to 6655 ft]

Roughness measurements were taken by starting from the beginning of the test road and driving to the end noting interval stationing. Measurements were then taken by starting at the end station and proceeding to the beginning station. For each section, an average of the forward and reverse measurements were determined. A summary of the average roughness data for the four surfacing sections is given in Appendix A.

TRAFFIC DATA

Logging trucks were the major traffic. Truck weights and traffic volume were determined by scale weights of trucks at the lumber mill where logs were delivered. For each pass of a loaded truck over the test section, an unloaded truck completed the round trip. One support vehicle (pick-up) was assumed for each round trip log haul. Other light traffic volumes, mostly hunter's pick up trucks or Forest Service administrative vehicles, were recorded by a traffic counter or estimated by Nez Perce personnel from previous traffic volume experience in the general area. A summary of traffic data is given in Appendix B.

MAINTENANCE

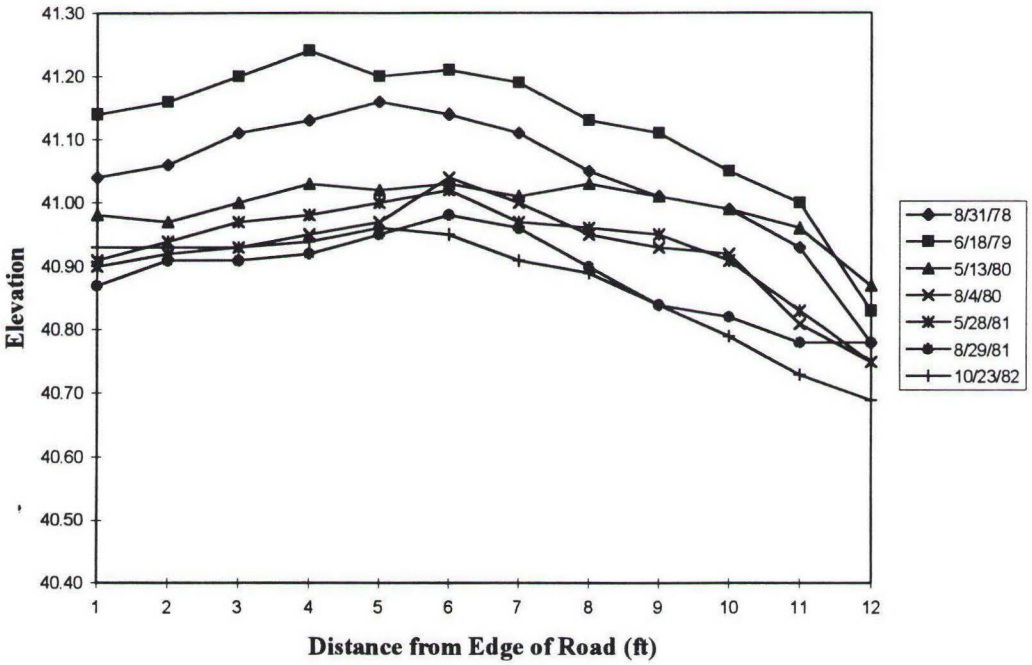
From the end of construction on 8/31/78, the only maintenance activity on the test section was road surface grading. No aggregate surfacing was added during the entire test period. Road blading occurred as follows:

8/31/78	-	end of season
7/03/79	-	mid season
9/30/79	-	mid season (light)
10/30/79	-	end season (light)
7/21/80	-	mid season
8/05/80	-	mid season
9/11/80	-	end season
6/15/81	-	mid season
7/30/81	-	mid season
9/24/81	-	mid season
7/21/81	-	mid season

CROSS-SECTION ANALYSIS

A typical change in cross-section over the test period is illustrated by figure 1. This is for a cross-sections taken on a straight road segment with a grade of 3.5%. Although cross-sections measurements extended from beyond the ditch to the edge of fill (at least 18 ft. if the section was a cut and fill), only the 12 ft. travel way is considered in all analysis.

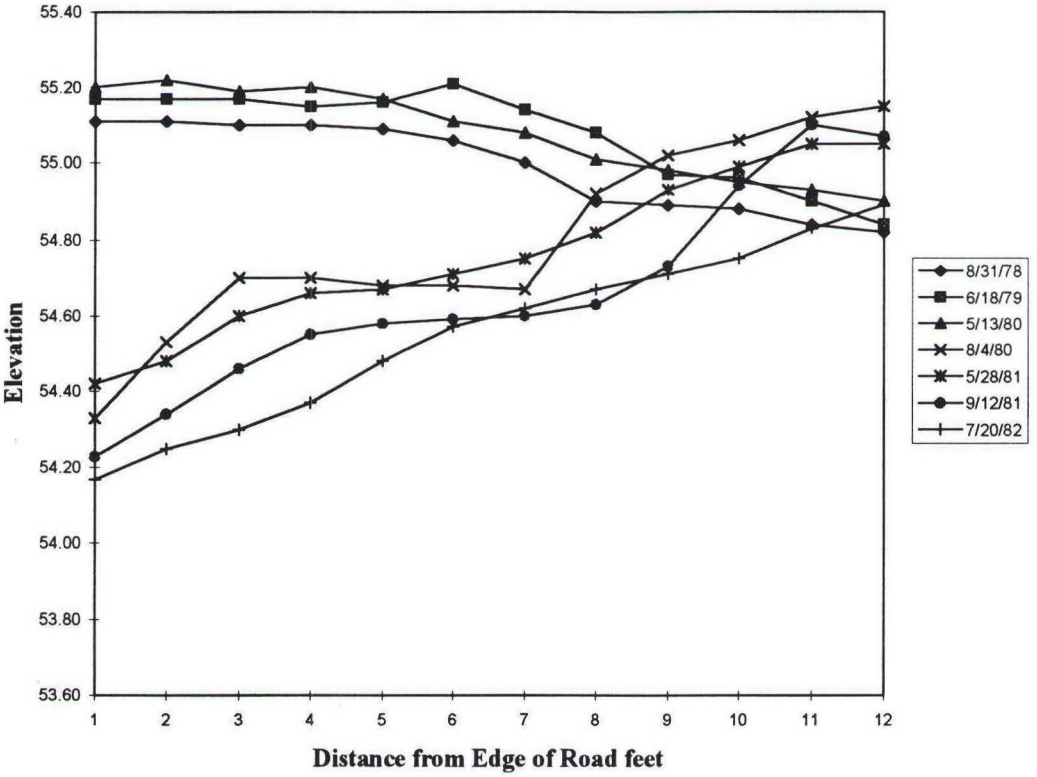
FIGURE 1 **Cross-Sections Elevation MS 10**



Elevation changes result from movement caused by traffic and maintenance blading and environmental effects. As can be noted in Figure 1, the general trend of cross-section elevations is lower toward the end of the testing period.

Figure 2 illustrates the cross-sectional elevation changes for a test location MS 16 which is on a sharp curve radius 210 ft. with a grade of -6%.

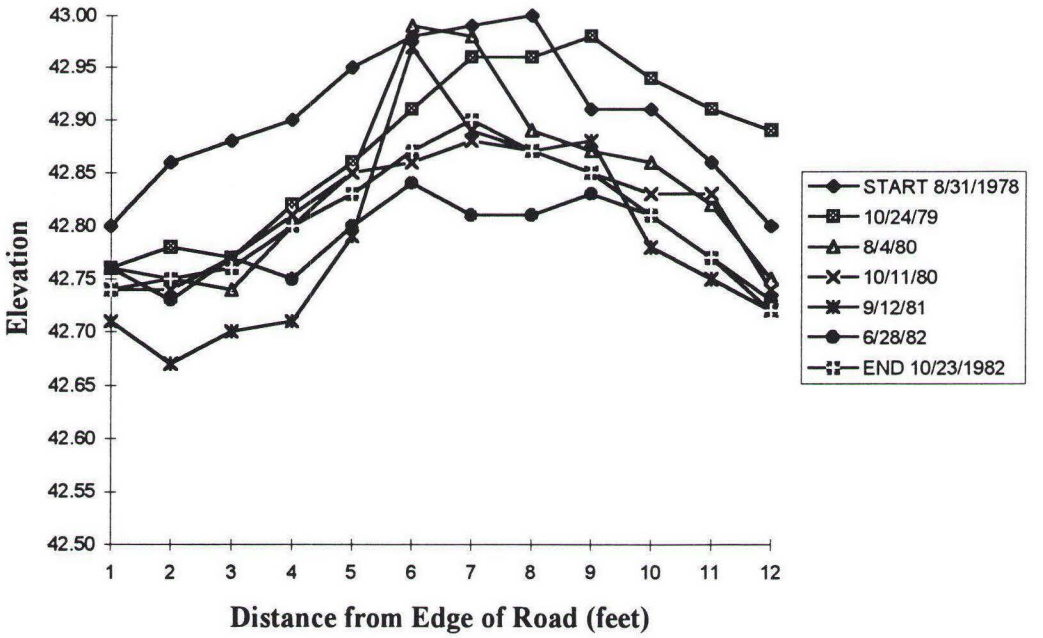
FIGURE 2 **Cross-Section Elevations MS 16**



As can be seen from figure 2, the effects of traffic on aggregate surfacing on a tight curve is very pronounced. Surfacing was pushed to the outside of the curve and even beyond the 12 foot road-way width. Part of the lost surfacing may be recovered if road ditches are pulled during maintenance blading. However, the long term trend indicates aggregate being shifted to the outside of the curve.

Figure 3 illustrates the cross-section elevation changes for a test on a curve radius 375 feet with a grade of -5%.

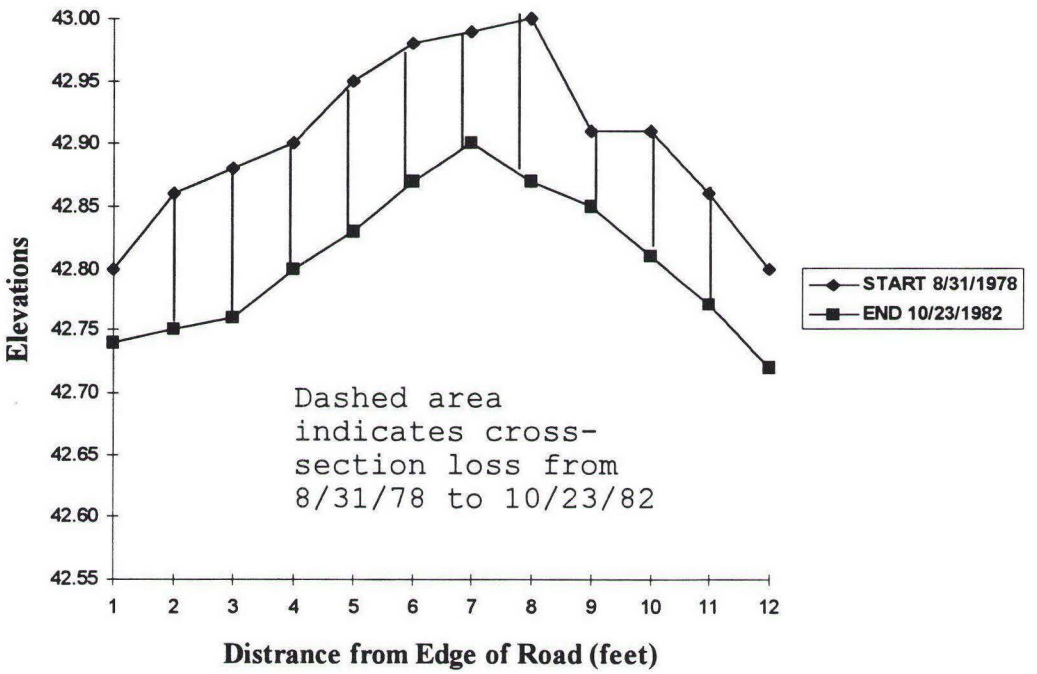
FIGURE 3 **Cross-Section Elevations MS 9**



AGGREGATE LOSS ANALYSIS

Aggregate loss results were calculated from changes in cross-section elevations. Each cross-section was assumed to be representative of the length of road section from midway between adjacent cross-sections. Volume of aggregate loss was calculated using the width of cross-section and the length of road section as previously defined. Since the Forests in Region 1 predict aggregate loss in terms of surface thickness decrease, volume loss results are converted to inches of surfacing lost over the test road section during the test period. Figure 4 shows the net cross-sectional area surface loss for MS 9 (filter) between the first cross-section elevations measured on 8/31/78 and the last cross-section elevations taken on 7/20/82.

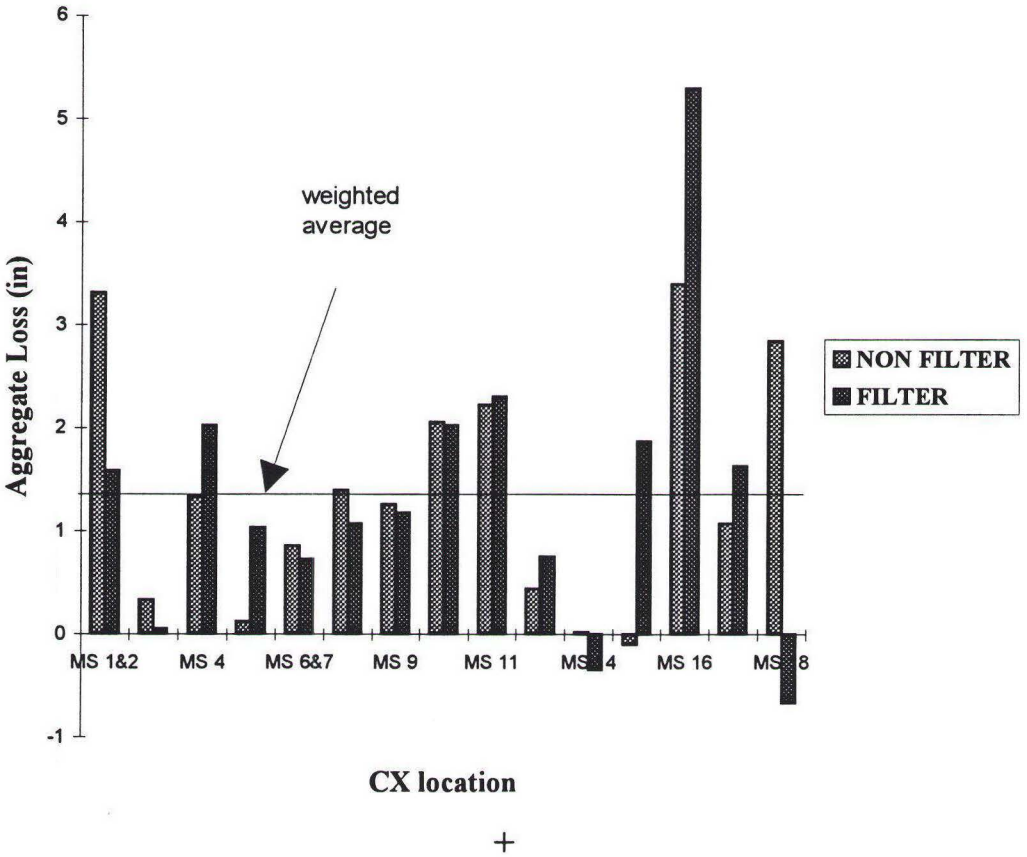
FIGURE 4 Start and End Cross-Sections MS 9



Using the average cross-section elevation change for each test location and calculating the mean change for the entire test road weighted by the distance

between each test location, results in a mean loss of 1.33 inches of aggregate surfacing for both the filter and non filter sections. Figure 5 shows the variation in loss for cross-section location from 1978-1982.

FIGURE 5 Aggregate Loss (in) Filter and Non Filter CX's



Aggregate Loss vs. Traffic

Figure 6 illustrates the changes in weighted mean surface loss for the road section with logging truck traffic. A fully loaded log truck of 80,000 lbs, an unloaded truck of 27,000 lbs and a service vehicle (pickup) of 6000 lb was counted as one round trip.

FIGURE 6 Surface Loss vs Cumulative Rd Trip Log Haul

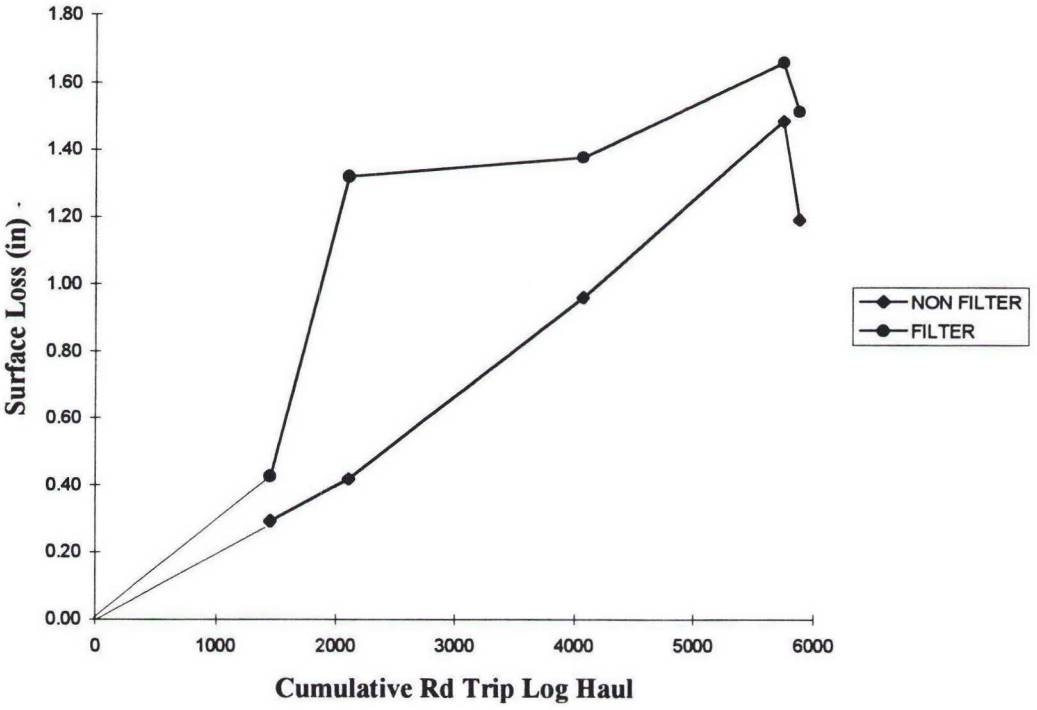
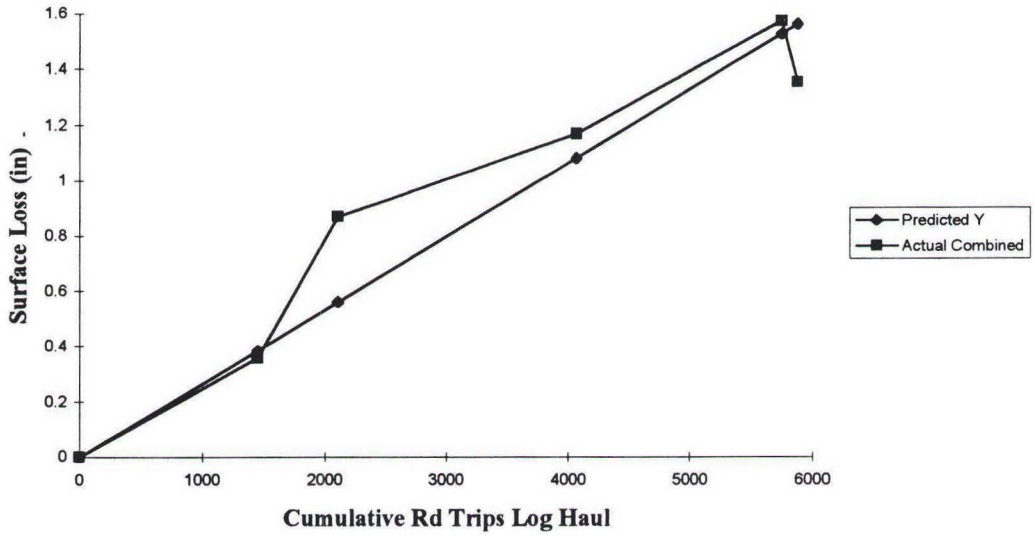


Figure 7 shows the surface loss for the combined filter and non filter sections compared with cumulative round trip log hauls.

FIGURE 7 Surface Loss Combined (in) vs Cumulative Rd Trips Log Haul



The average BF per log haul was 4800 BF. 5880 total loads were hauled over the four year period. The average surface loss in millions of board feet hauled was calculated at 18.10 MM BF/inch surface loss . The Nez Perce routinely uses a figure of 10 MM BF/inch surface loss in commensurate share calculations.[6]

The recently completed NATC test[4] resulted in surface losses varying between 34.5 MM BF/inch loss for high tire pressure log haul and 26.3 MM BF/inch loss for low tire pressure log haul. The test was carried out in dry conditions only and was designed so one lane of a two lane road was used by loaded and unloaded log trucks while the adjacent lane was used by light trucks and cars. Losses were determined for log traffic alone and light truck/car traffic

alone. This allowed a direct comparison of the aggregate surface losses contributed to log truck haul to that of a light vehicle.

Over the same four year period, 13,650 light trucks and cars were recorded using the road section. Figure 8 shows the yearly light trucks and cars and log haul traffic and the effect on yearly surface loss.

FIGURE 8 **Yearly Surface Loss (in) vs Traffic Type**

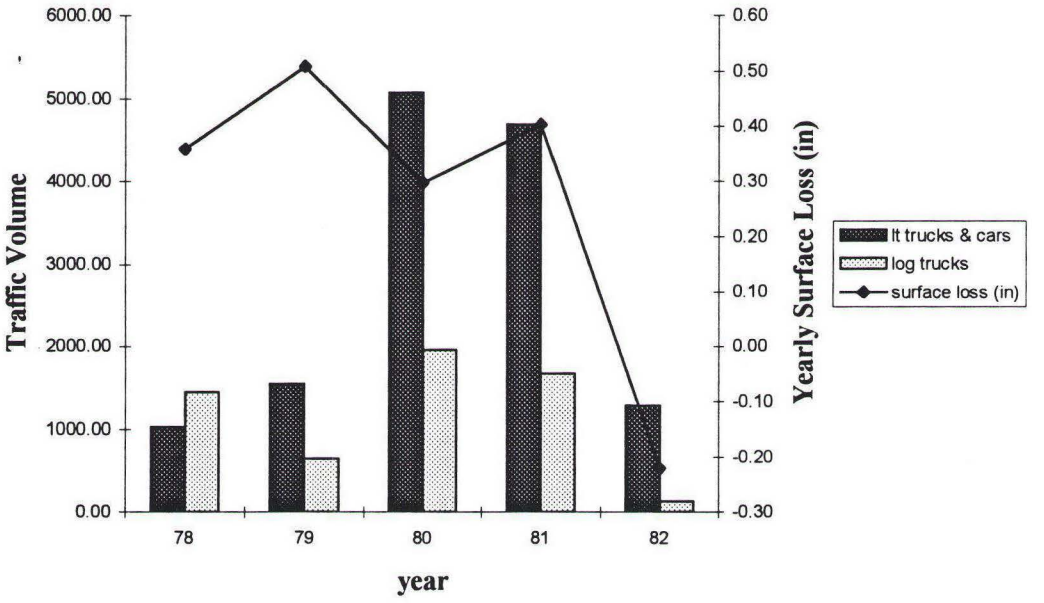


Figure 9 show the loss with log haul alone.

FIGURE 9 Yearly Surface Loss (in) vs Yearly Log Haul Traffic

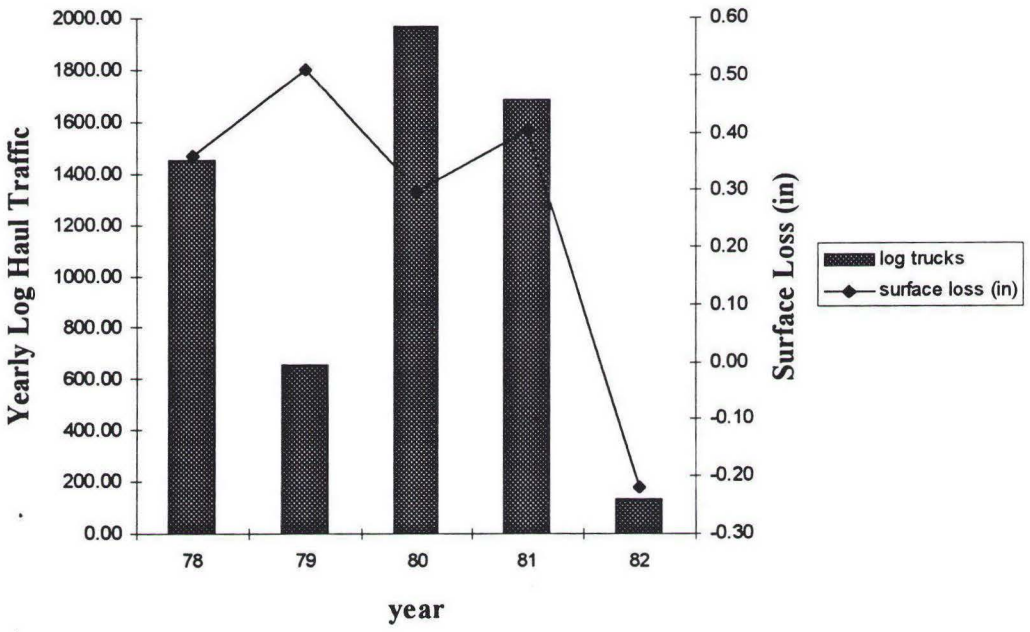
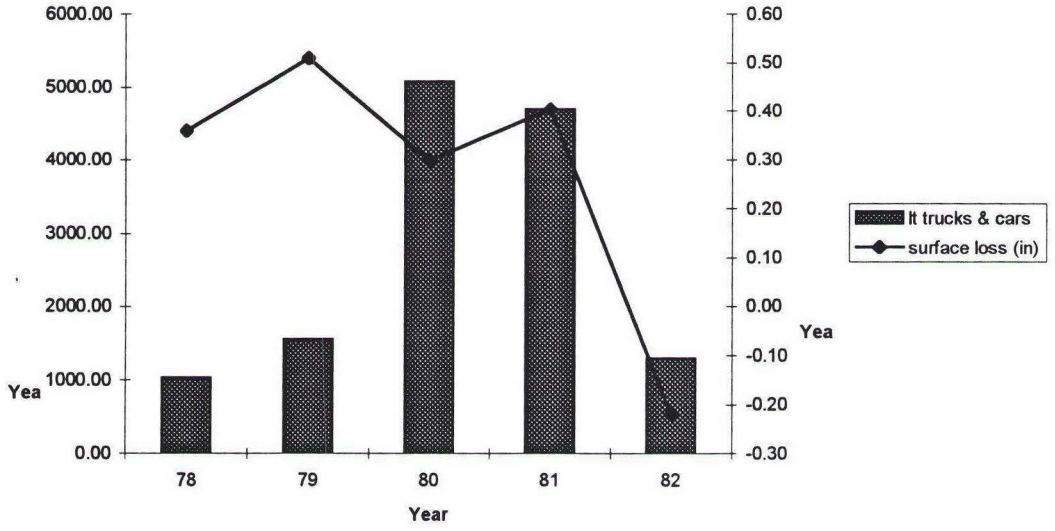


Figure 10 shows the yearly surface loss for light truck and car traffic alone.

FIGURE 10 **Yearly Surface Loss (in) vs Yearly Light Truck and Car Traffic**



The correlation with yearly surface loss and traffic is much greater with log haul then light truck and car. Table 4 gives the correlation between total traffic, light trucks and cars, and log haul trucks.

TABLE 4 surface loss correlation coefficient

total traffic	0.372307
light trucks & cars	0.266369
log haul trucks	0.578243

WORLD BANK HDM MODEL SURFACE LOSS PREDICTION

The World Bank HDM model[7] was used to predict surface loss for the test road as a comparison to measured results. Data inputs to the model required: (1) surfacing characteristics such as thickness, gradation and PI, (2) road geometry information (curvature and grade), (3) environmental information such as average rain-fall and elevation (4) yearly traffic volume and type.

The HDM Model used to predict unpaved road deterioration is derived from data taken from low volume roads that are traveled year-round. Also, the climatic and environmental conditions of the roads were different than the test road environment (tropical climate, generally low elevations, high average rain-fall).

The model requires yearly ADT and does not allow for six month of essentially no traffic and a considerable snow pack. The following assumptions were necessary for determination of inputs required by the HDM Model:

(1) The average of two seasons ADT (six months per season) were used for the yearly ADT.

(2) Rain-fall yearly averages were determined from the average precipitation over the five year for the travel season only (May through October)

(3) Surface loss comparisons were made on the interval 1978 through 1981.

(4) No surface loss occurred during the winter (snow-pack) season.

Data Used for HDM Input

Rain-fall yearly average	2.85 in/mon	
VEHICLE TYPE	ADT	
	1978-1980	1978-1981
Log Trucks Loaded	3	10
Log Trucks Unloaded	3	10
Light Trucks and Cars	7	27

Predicted Surface Loss from HDM Model

	SURFACE LOSS (in)	
	HDM	MEASURED
End of 1979 (2 yrs)	0.76	0.87
End of 1981 (4 yrs)	1.62	1.57

ROUGHNESS ANALYSIS

Roughness measurements were taken as described in previous sections. Figure 11 shows the roughness progression with time.

Table 5 shows the increase in roughness and the traffic volume and type. Roughness was taken soon after blading and before the next blading.

TABLE 5

ΔQI	TRAFFIC VOLUME		
	Log Trucks	Light Vehicles	Total
42	1069	2312	3381
45	393	998	1391
34	1120	2665	3785
20	166	1035	1201

Figures 12 and 13 show the relationship between traffic volume and increase in roughness.

FIGURE 12 **Change in QI vs Traffic Volume**

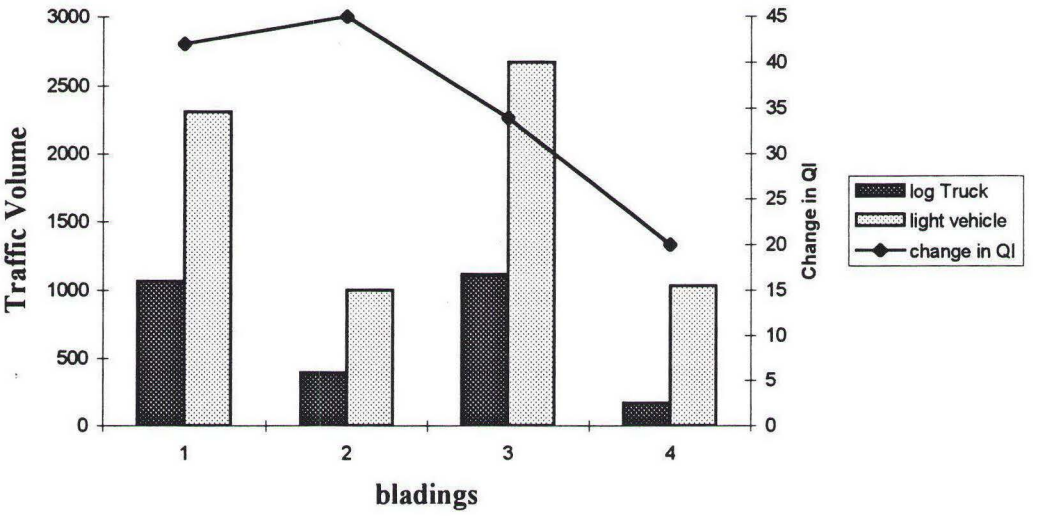
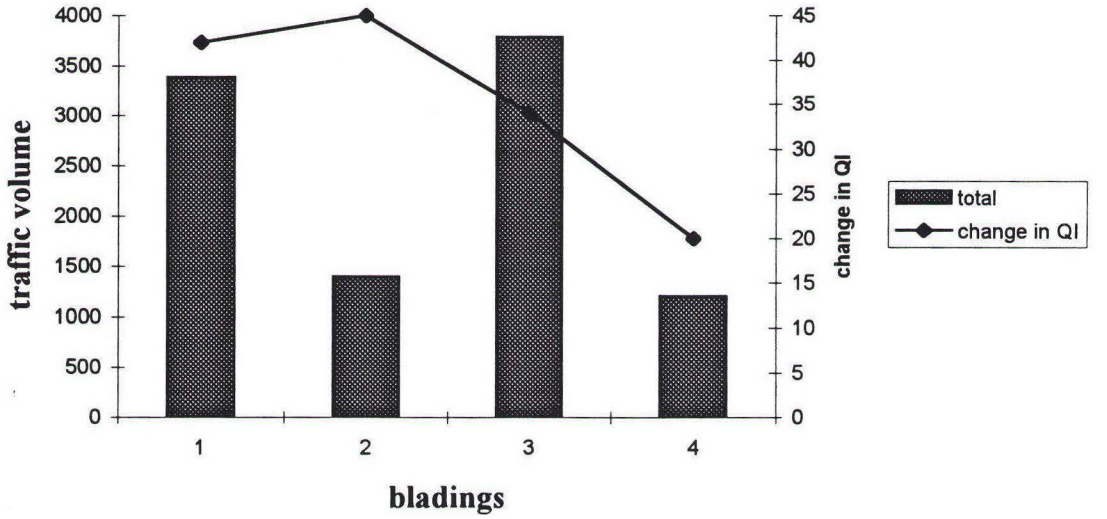


FIGURE 13 **Change in QI vs Total Traffic Volume**



Correlation between traffic and roughness is given in Table 6.

TABLE 6	QI roughness correlation
total traffic	0.30
light trucks & cars	0.22
log haul trucks	0.44

The correlation between increase in roughness and traffic is similar to the ones calculated for surface loss and traffic although the correlation between roughness increase and log haul traffic is not nearly as strong.

Roughness and Cross-section Variation

Since longitudinal variations in the road surface (rutting, rills, etc.) is important in surface thickness design and especially sediment runoff from the road surface, correlation between roughness and longitudinal variation was investigated. Variance was calculated for each cross-section and averaged over the road section with thickness of 4, 8, and 12 inches. The average variance for all cross-sections in each of the road sections with equal surface thickness was correlated with the surface roughness measurements. Only those cross-sections measurements taken the same day or at maximum one day earlier or later were considered in the correlation determination. Table 7 summarizes the results.

TABLE 7	QI roughness correlation with cross-section variance
4 inch surface	0.24
8 inch surface	-0.25
12 inch surface	0.21
average	0.26

If variance of the elevation of cross-sections is an indicator of surface rutting or rilling, the correlation coefficients indicate roughness measurements would not be an efficient predictor of road rutting.

SUMMARY

Surface loss over the test period of four years indicated an average loss of 1.62 inches for 27.8 MM BF of logs hauled. This results in a rate of loss of 1 inch per 18.1 MM BF hauled and compares with the rule of thumb used by the Nez Perce of 10 MM BF/in. The predicted loss using the World Bank HDM Model with appropriate assumptions was 1.57 inches of surface loss over the four year period. The NATC test resulted in losses between .29 inch and .38 inch per 10 MM BF hauled. Table 8 summarizes the comparisons.

TABLE 8

TEST		MM BF/ in. Loss	Environmental and other Conditions
HORSE CREEK		18.6	seasonal precipitation 1.83 in/mon ave. combined traffic (47% log haul vehicles) 5 year test
NATC	High Pressure	34.5	dry - log haul traffic only
	Low Pressure	26.3	dry - log haul traffic only 1 year test
WORLD BANK		18.2	ave precipitation 1.83 in/mon combined traffic (47% log haul vehicles) 2 year test (four seasons - six months e

Log haul traffic and surface loss gave a correlation coefficient of 0.58. Correlation between light traffic/cars and loss was 0.27. The relative size of the coefficients support the assumption that log haul results in far more surface loss then lighter traffic.

Correlation between roughness increase and traffic volume followed the same trend with correlation coefficients of .44 for log haul and .22 for light trucks/cars. This also supports the assumptions that roughness generation (washboarding, pot holing) by light vehicles may be equivalent to that by log hauls especially during drier periods.

There was very little correlation between roughness and average elevation variance for cross-sections on sections with equal surface thickness. Values ranged from .24 for the 4 inch surface to -.25 for the 8 inch surface. From this data, there is little to support using roughness measurements for road rutting estimates.

Cross-sections on curves showed a definite surface movement to the outside of the curved part of the roadway. Surface losses in the curved sections were consistently greater then losses on straight sections.

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2. J. Lund. Surfacing Loss Study. Region 6, Forest Service, U. S. Department of Agriculture. Portland, Oregon, 1976.

3. R. F. Hinshaw and J. L. Northrup. Predicting Subgrade Moisture Under Aggregate Surfacing, Fifth International Conference on Low Volume Roads, Raleigh, North Carolina, May 19-23, 1991.

4. Nevada Automotive Test Center. Road Maintenance Ratios Commensurate Share Test Dry Weather Test Results, San Dimas Technology and Development Center, Contract Number 53-9JA9-2-1Q044, June 1994

5. R. F. Hinshaw, Calibration of Cox Roughness Meter , Personal Correspondence, Region 1, Forest Service U.S.D.A., Missoula, Mt.

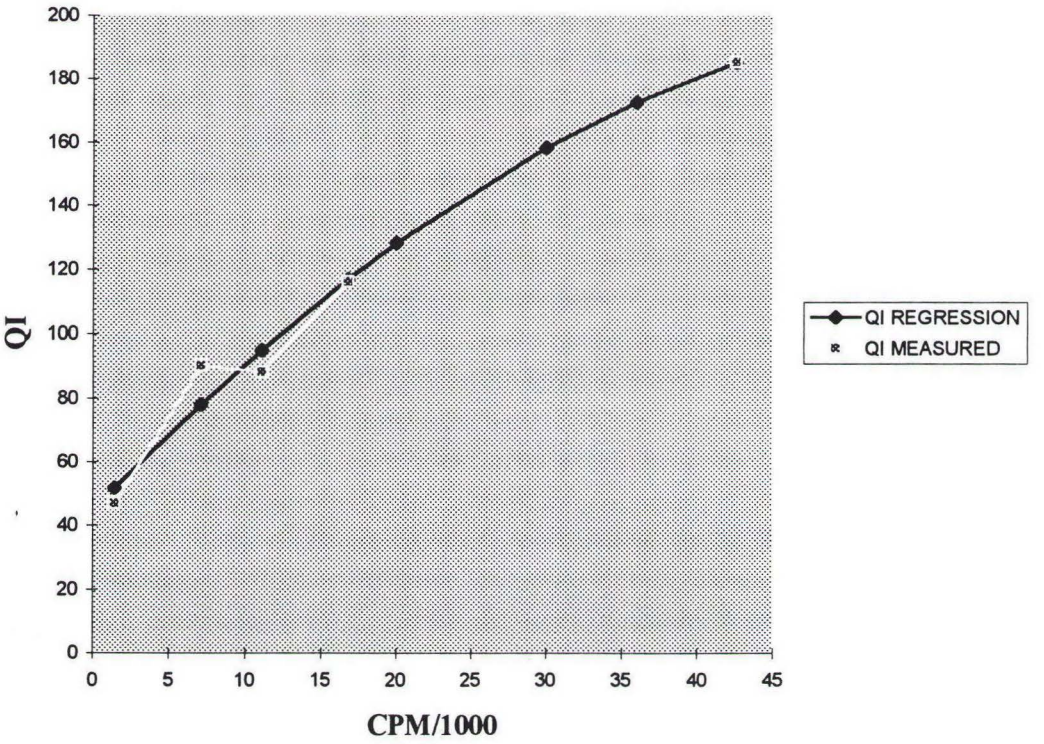
6. M. Cook, Surface Loss Estimate for Log Haul Aggregate Replacement, Personel Communication, Nez Perce N.F., 1989

7. T. Watabatada and Others. HDM-III, World Bank, Licensed for distribution Center for Microcomputers in Transportation (McTrans), U. of Florida, 512 Weil Hall, Gainesville, FL.,

APPENDIX A

Calibration curve for roughness meter taken from Hinshaw[5].

FIGURE 14 Calibration of Cox Meter



Regression equation QI = 44.761 + 4.947*(CPM/100) - .039*(CPM/1000)^2

Appendix A continued

TABLE 7 ROUGHNESS MEASUREMENTS

Date		8 inch forward	8 inch reverse	12 inch forward	12 inch reverse	4 inch forward	4 inch reverse
9/10/80	end	16221	15757	15903	17668	15810	16145
5/28/81	beginning	10095	9100	8226	7770	9851	8468
6/16/81	after	6278	5294	5979	5637	5844	5203
7/30/81	before	16136	17298	17466	16803	16131	16870
8/6/81	after	12740	13295	11632	13040	11736	13430
9/9/81	before	22389	21202	21837	21971	22235	22718
9/19/81*	before	20577	20221	22254	20819	21230	20112
*2nd set 9/25/81	after	8247	7820	7741	8033	7891	8528
11/5/81	end	13199	12909	12281	13469	12597	13327
7/1/82	beginning	4644	5588	8722	10223	5917	5454
7/19/82	before	6066	4142	6697	6866	5881	6576

APPENDIX B

APPENDIX B

Traffic Data

	Cars and Light Trucks Inc Vol	Log Haul Rd Trip* Inc Vol	Cars and Light Trucks Cum Vol	Log Haul Rd Trip* Cum Vol	Cars and Light Trucks Inc ADT	Log Haul Rd Trip* Inc ADT
total 78	1032	1450	1032	1450	1	1
total 79	1554	655	2586	2105	2	2
total 80	5078	1964	7664	4069	6	4
total 81	4698	1679	12362	5748	5	2
total 82	1288	132	13650	5880	2	0

* Round trip log haul consisted of one loaded log truck (ave. 80000 lbs.), one unloaded log truck (ave. 27000 lbs.) and one supporting pickup.